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EFFECTS OF COMPRESSIBILITY AND LARGE ANGLES OF YAW ON PRESSURE INDICATED BY A TOTAL-PRESSURE TUBE

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EFFECTS OF COMPRESSIBILITY AND LARGE ANGLES OF YAW ON PRESSURE INDICATED BY A TOTAL-PRESSURE TUBE

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SUMMARY

The effects of compressibility and angle of yaw on the pressure measured by a round-nose and a flat-nose total-pressure tube have been investigated. The tests were conducted in the Langley rectangular high-speed tunnel at Mach numbers from 0.3 to 0.9 for angles of yaw from 0° to 180°.

The results indicated that no error was incurred in the measurement of total pressure by either tube for angles of yaw from 0° to 10° in the Mach number range investigated. At constant Mach numbers, the round-nose tube had a linear variation of total-pressure error with angle of yaw at angles ranging from 50° to 70°. This characteristic is desirable in yaw heads of the Y-type. The flat-nose tube had a nonlinear variation of total-pressure error with angle of yaw in this range.

INTRODUCTION

Available information on the pressure measured by total-pressure tubes yawed with respect to the air stream was limited to small angles of yaw and low Mach numbers. An investigation has therefore been conducted to determine the pressure measured by a total-pressure tube for Mach numbers from 0.3 to 0.9 over the angle-of-yaw range from 0° to 180°. Two types of total-pressure tube were tested, a round nose and a flat nose. The information obtained in this report should facilitate analysis of flow-direction measurements and other aerodynamic properties.

APPARATUS AND METHODS

The tests were made in the Langley rectangular high-speed tunnel, which is an induction-type tunnel having a 4- by 18-inch test section. Atmospheric air is induced to flow through the tunnel by an induction nozzle located downstream from the test section. Except for a small loss of pressure resulting from the passage of air through the screens at the tunnel entrance, the total pressure at the test section is approximately equal to atmospheric pressure. This wind tunnel is basically similar to the N.A.C.A. high-speed wind tunnel described in reference 1.

The round-nose and the flat-nose total-pressure tubes used in this investigation were made of brass tubing having an outside diameter of 0.125 inch and walls 0.0254 inch thick. The tubes were constructed in the form of an L with a head 1 inch long at an angle of 90° to the supporting spindle (fig. 1).

The total-pressure tube was mounted in the center of the test section with the supporting spindle normal to the tunnel wall and passing out through a hole of approximately $\frac{1}{8}$-inch diameter drilled in the wall. The head of the tube could be rotated about the spindle axis through the angle-of-yaw range and could be locked in any desired position.

SYMBOLS

H total pressure measured above absolute zero with air at rest

H' pressure indicated by total-pressure tube

M free-stream Mach number

M_x Mach number at nose of tube computed on assumptions that flow is adiabatic and that H' equals static pressure at nose of tube

p_o free-stream static pressure

q free-stream dynamic pressure $\left(\frac{1}{2}\rho V^2\right)$

ρ density, slugs per cubic foot

V velocity of mean free stream, feet per second

ψ angle of yaw of instrument head

PRECISION

It is believed that practically all the errors to which the quantities measured in this investigation are subject are of an accidental nature. The variation in Mach number in the test section parallel and normal to the tunnel axis is insignificant for these tests. Tunnel constriction effects should be negligible because of the small size of the total-pressure tube relative to the tunnel size. Air-flow misalinement and the error in alinement of the total-pressure tube are within $\pm\frac{1}{4}^{\circ}$.

The free-stream static pressure and the error in total pressure as indicated by the total-pressure tubes were measured by visual observation of liquid-filled manometers. Liquids of different densities were used in the manometers for various ranges of pressure differences to insure large rises of the liquid and thereby minimize the errors in readings. An indication of the magnitude of the accidental error involved in these data is given in figures 2(a) and 2(b), each of which shows the scatter for two tests with the total-pressure tube at an angle of yaw of 65°. Check points are indicated by flagged symbols.

The data presented have been corrected for the total-pressure loss resulting from the passage of the air through the screens at the tunnel entrance. The amount of this loss was determined by measurements made in the test section and in the low-speed region ahead of the entrance cone and was checked by computations of the pressure loss through screens.

RESULTS AND DISCUSSION

The variation of total-pressure error, in terms of total pressure, with Mach number for the round-nose and for the flat-nose tubes is shown in figures 2(a) and 2(b), respectively. At constant angles of yaw of 20° or greater, the total-pressure error increased with increasing Mach number. The rate of change of the error with Mach number increased as the angle of yaw was increased from 20° to approximately 90°, where the rate of change of the error was at a maximum. At angles of yaw from 90° to 180°, the slopes decreased with increasing angle of yaw.

The variation in the total-pressure error with Mach number became increasingly irregular in the free-stream Mach number range from 0.7 to 0.3 for angles of yaw between 110° and 150° (figs. 2(a) and 2(b)). If the flow is assumed to be adiabatic and the pressure measured by the tube H' is assumed to correspond to the static pressure of the flow in the vicinity of the opening in the nose of the tube for these conditions, the local Mach number M_x can be computed. The value of $\frac{H - p_o}{H}$ for a Mach number of 1.0 would be 0.472. It can be seen that the irregularities in the curves occur near a value of $\frac{H - H'}{H}$ of 0.472 and are possibly due to the formation or movement of shock.

The variation of total-pressure error, in terms of free-stream dynamic pressure, with Mach number is shown in figure 3. For angles of yaw greater than 20°, the total-pressure error had a small, nonlinear variation with Mach number. This variation became irregular at the higher angles of yaw and the most pronounced directional changes occurred near 90°. No error was incurred in the measurement of total pressure by either the round-nose or the flat-nose tube over the Mach number range extending from 0.3 to 0.9 for an angle-of-yaw range from 0° to 10° (figs. 2 and 3).

The variation of the total-pressure error, in terms of total pressure, with angle of yaw is presented in figure 4 for several Mach numbers. The curves were obtained by cross-plotting the data presented in figure 2. The results show that the total-pressure error increased with increasing the angle of yaw from 20° to approximately 87° and then decreased as the angle of yaw was increased to 130°.

At an angle of yaw of 130°, the pressure measured at the nose of each total-pressure tube was approximately the same for equal Mach numbers and was below free-stream static pressure p_o at all speeds. The relation given by

$$\frac{H - p_o}{H} = 0.85\left(\frac{H - H'}{H}\right)$$

for either tube at an inclination of 180° to the air stream is correct within ±2 percent of $\frac{H - p_o}{H}$ over the Mach number range investigated. This agreement presents a possible method of determining static pressure by means of a simple instrument that may be useful in some installations.

The variation in the total-pressure error, in terms of the stream dynamic pressure, as a function of angle of yaw for constant Mach numbers is shown in figure 5, a cross plot of the data in figure 3. Whereas the flat-nose tube had a nonlinear variation of total-pressure error with angle of yaw over an angular range from 50° to 70° for constant Mach numbers, the round-nose tube had a linear change - an indication that the round-nose tube would be desirable for use in yaw heads of the Y-type. A Y-type yaw head using round-nose tubes at an included angle of 120° should give a linear variation in calibration factor over an angular range of ±10°.

In order to give an indication of possible effect of compressibility on the calibration factor of a yaw head, the slopes of the curves of figure 5(a) are shown in figure 6 for angles of yaw between 50° and 70°. This curve indicates a small effect of compressibility on the calibration of a yaw head having round-nose tubes if the yaw head support is assumed to have negligible influence.

CONCLUSIONS

Tests made to determine the effects of compressibility and angle of yaw on the pressure measured by a round-nose and a flat-nose total-pressure tube indicated that:

1. Total-pressure tubes of the type tested in this investigation would give true total pressure for angles of yaw of 0° to 10° for Mach numbers from 0.3 to 0.9.

2. At constant Mach numbers, the round-nose tube had a linear variation of total-pressure error with angle of yaw at angles ranging from 50° to 70°. The flat-nose tube had a nonlinear variation of the total-pressure error with angle of yaw in this range. The round-nose tubes set at an included angle of 120° should therefore be desirable for use as components of a Y-type yaw head. This yaw head should give a linear variation in calibration factor over an angular range of ±10°.

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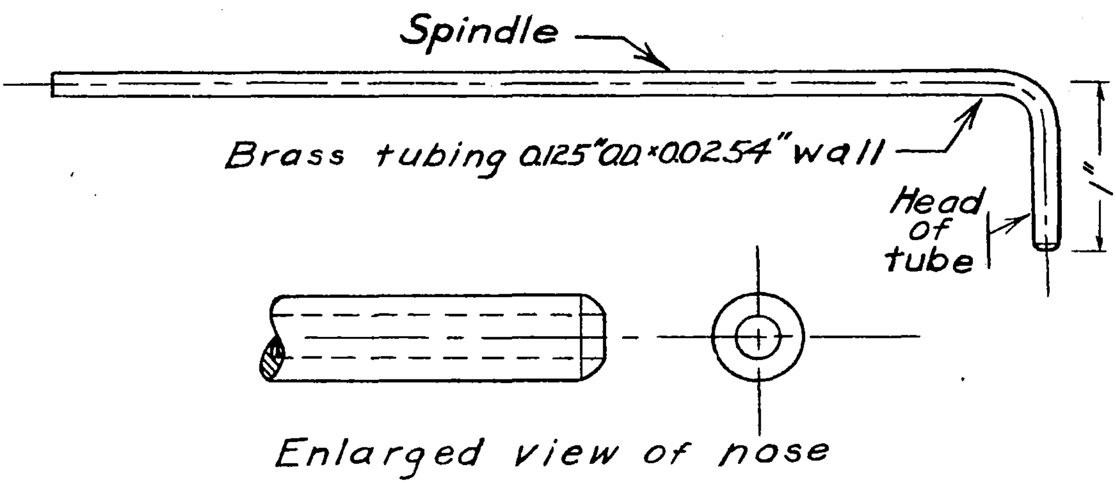
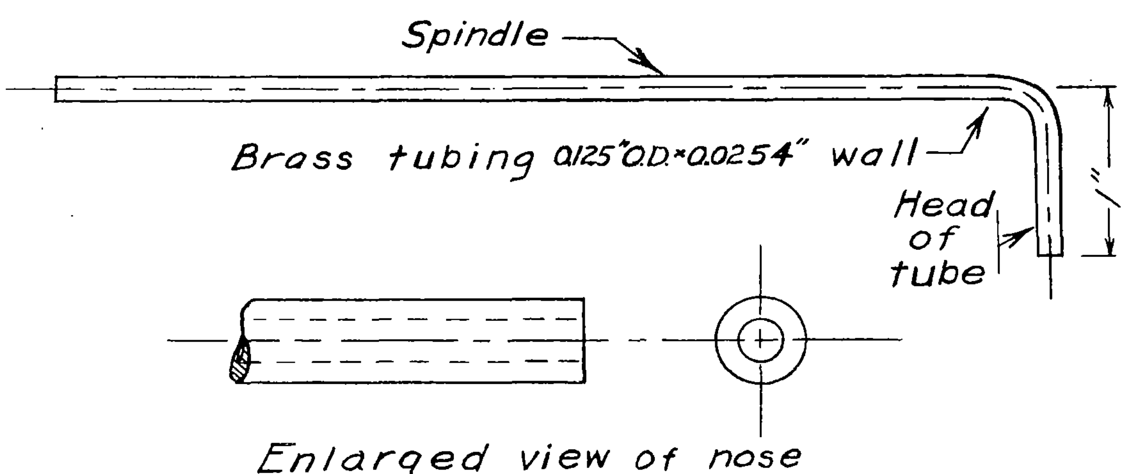
REFERENCE

1. Stack, John: The N.A.C.A. High-Speed Wind Tunnel and Tests of Six Propeller Sections. NACA Rep. No. 463, 1933.



(a) Round nose.



(b) Flat nose.

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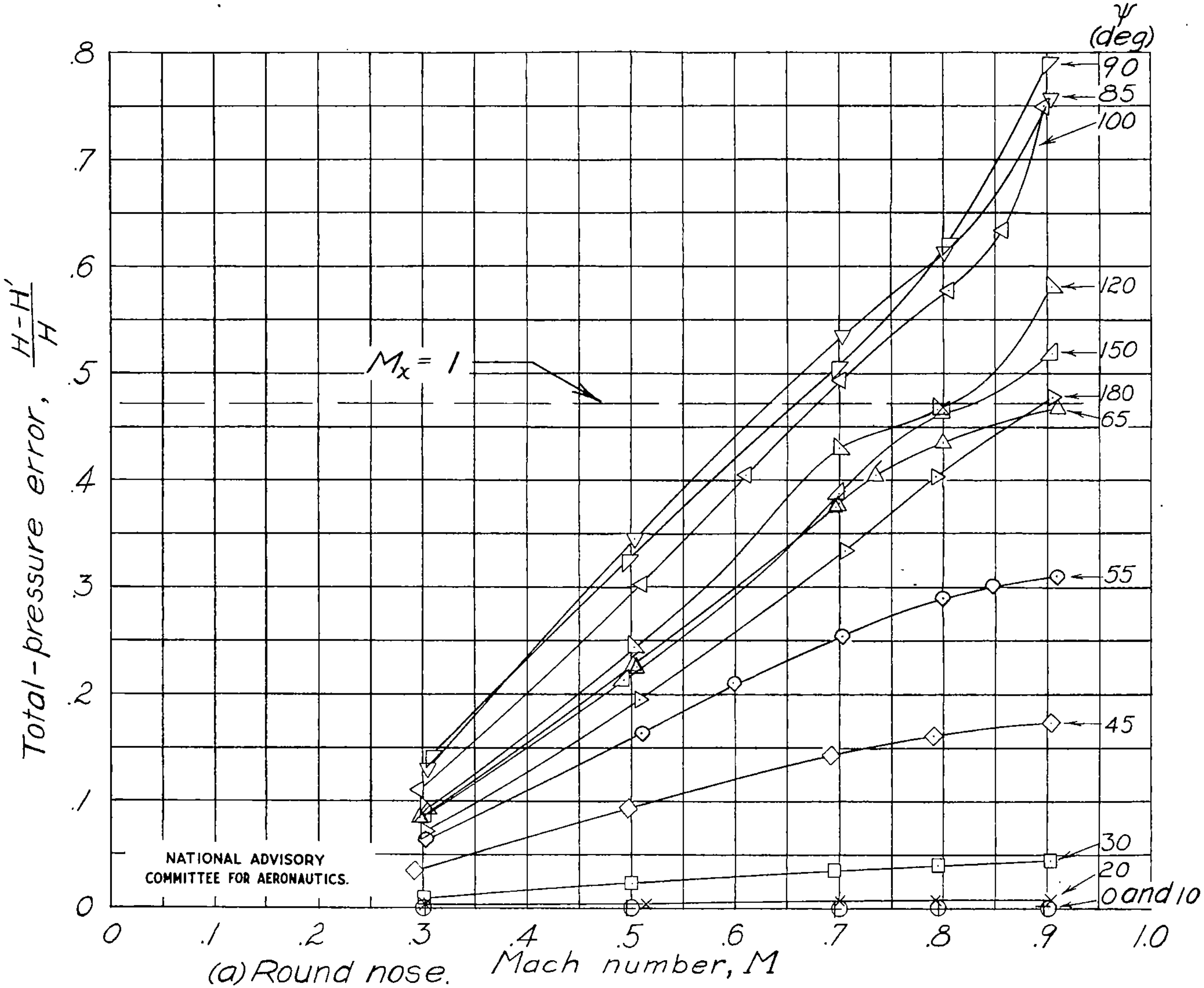
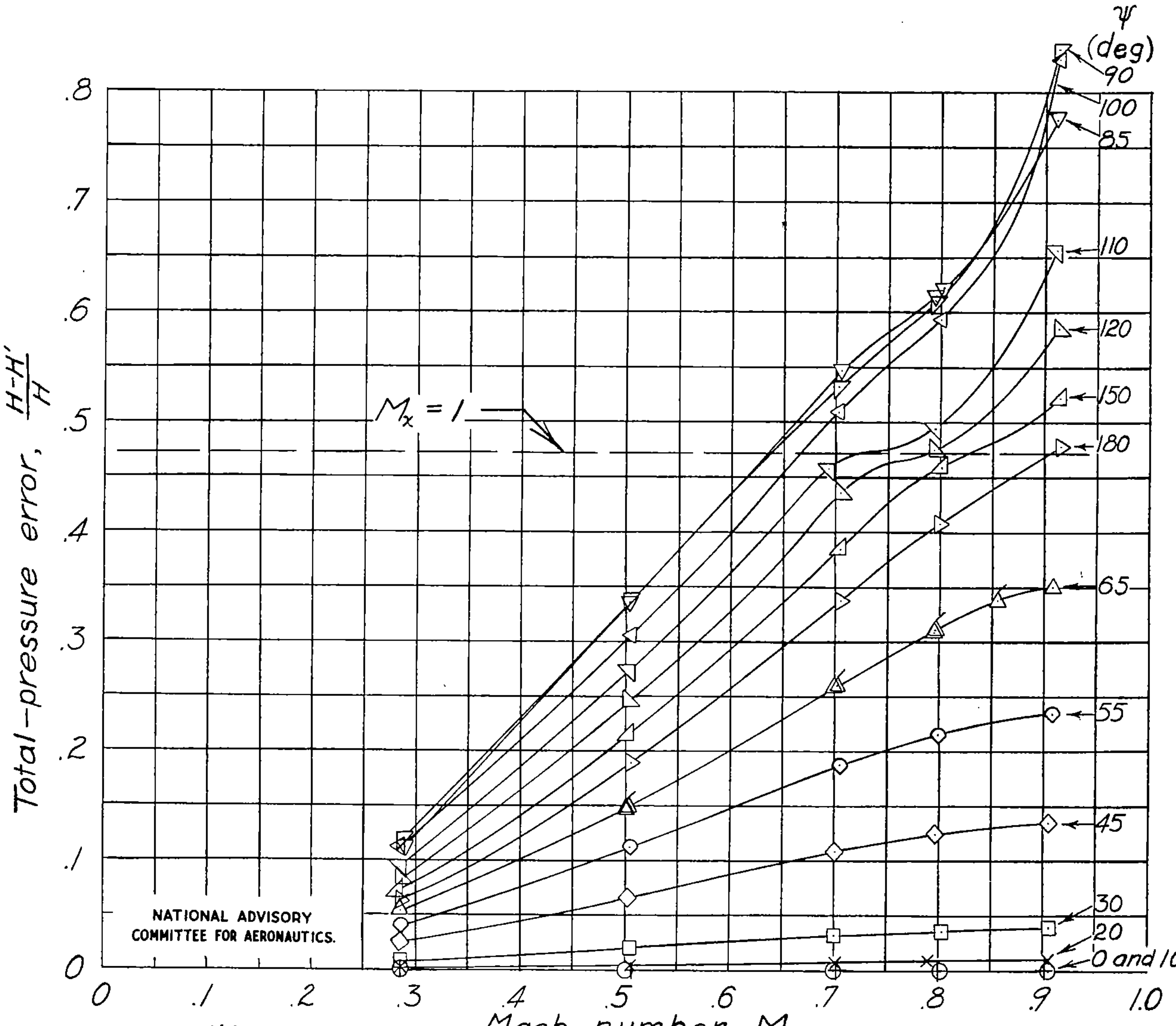
Figure 1.– Total-pressure tubes.



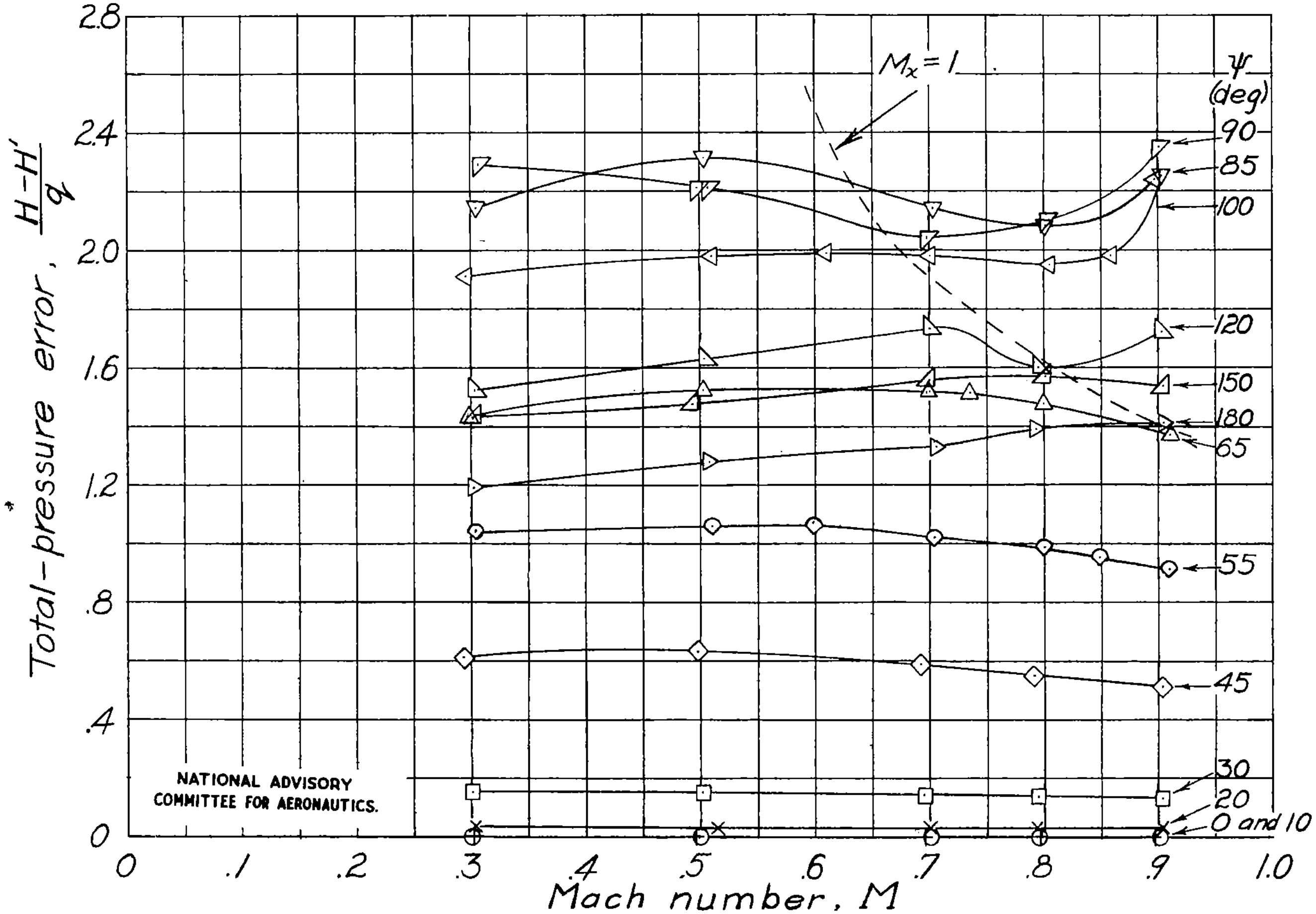
(a) Round nose.

Figure 2.- Variation of total-pressure error in terms of total pressure with Mach number for constant angle of yaw.



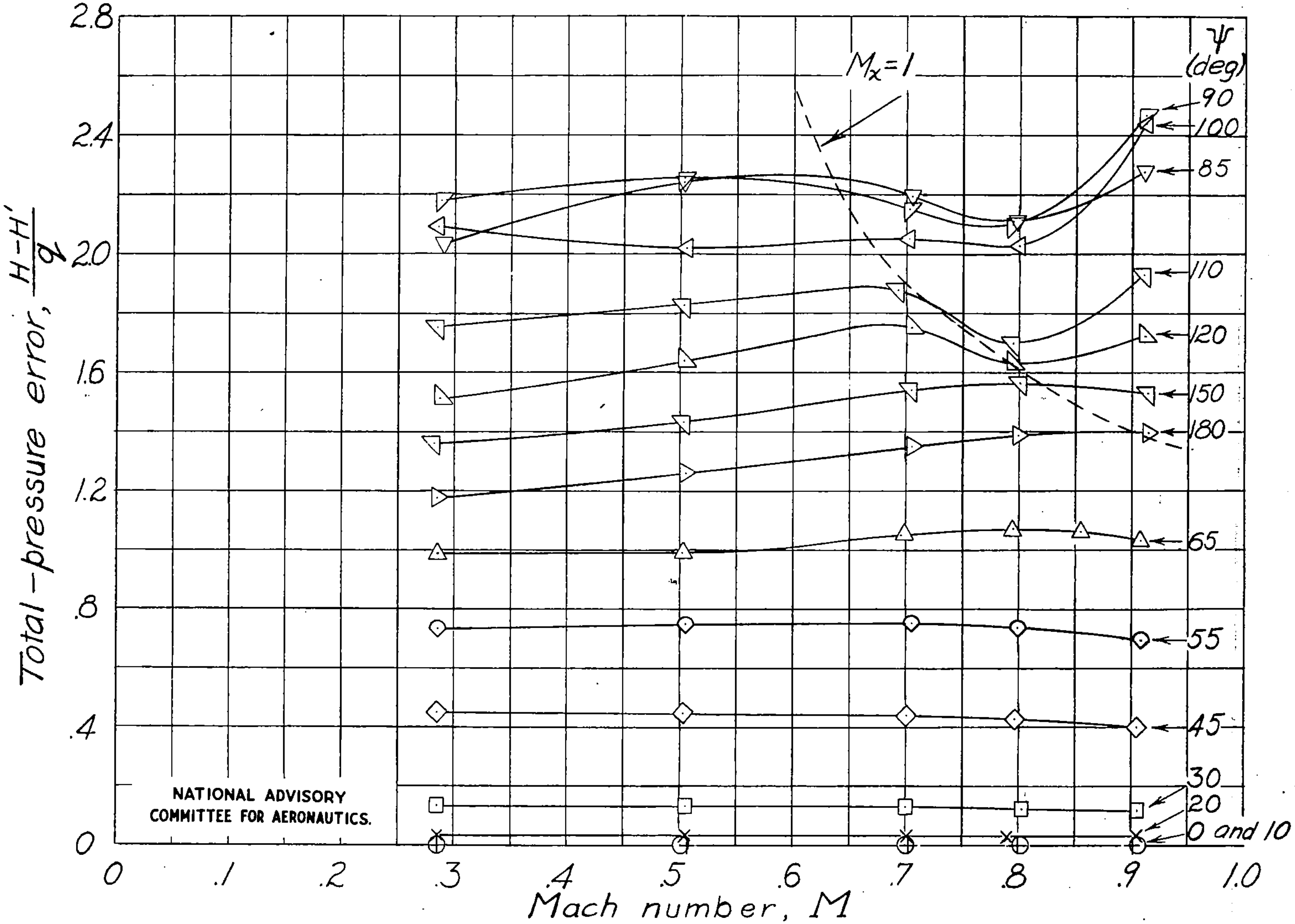
(b) Flat nose.

Figure 2.-Concluded.



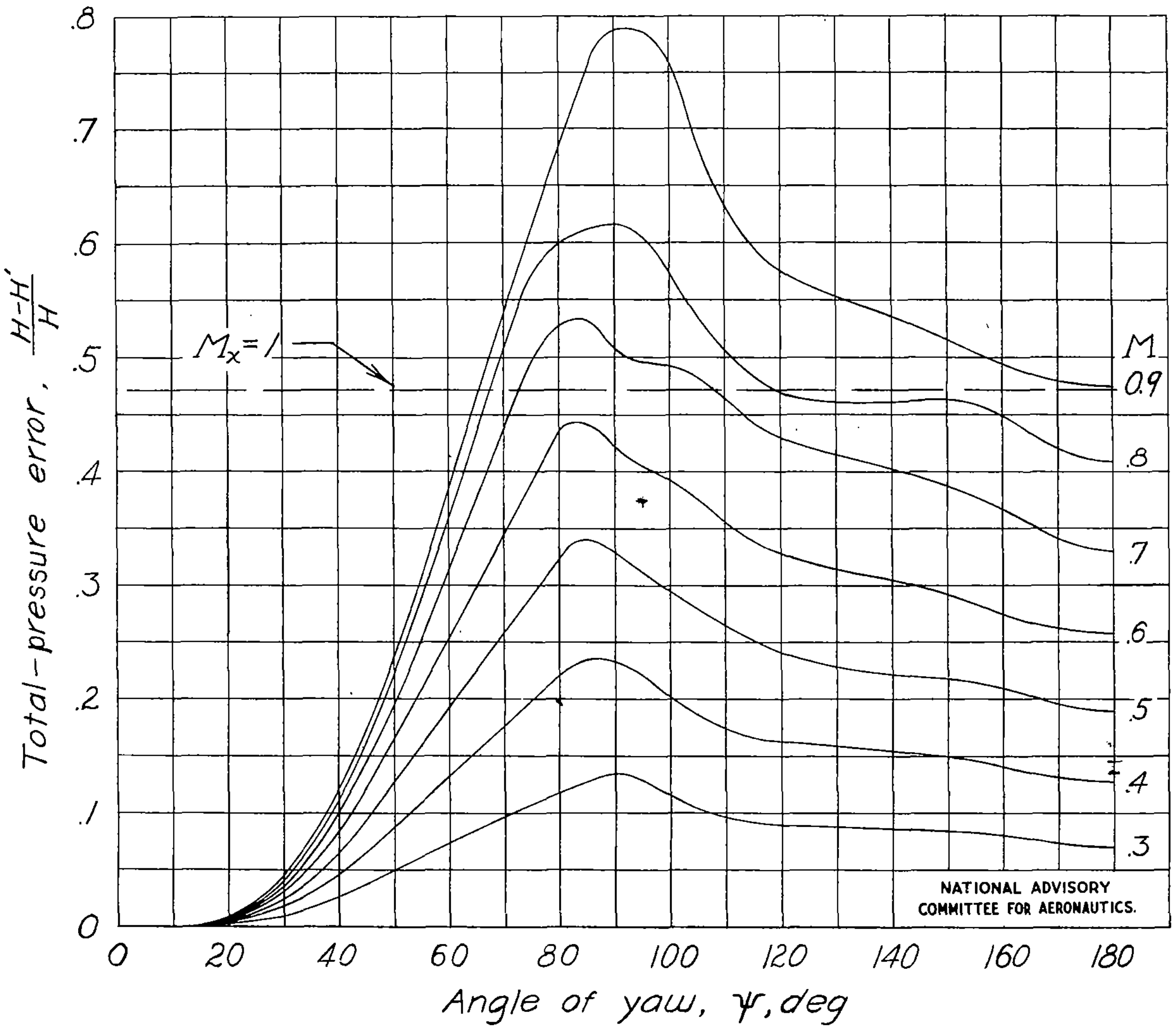
(a) Round nose.

Figure 3.- Variation of total-pressure error in terms of dynamic pressure with Mach number at constant angle of yaw.



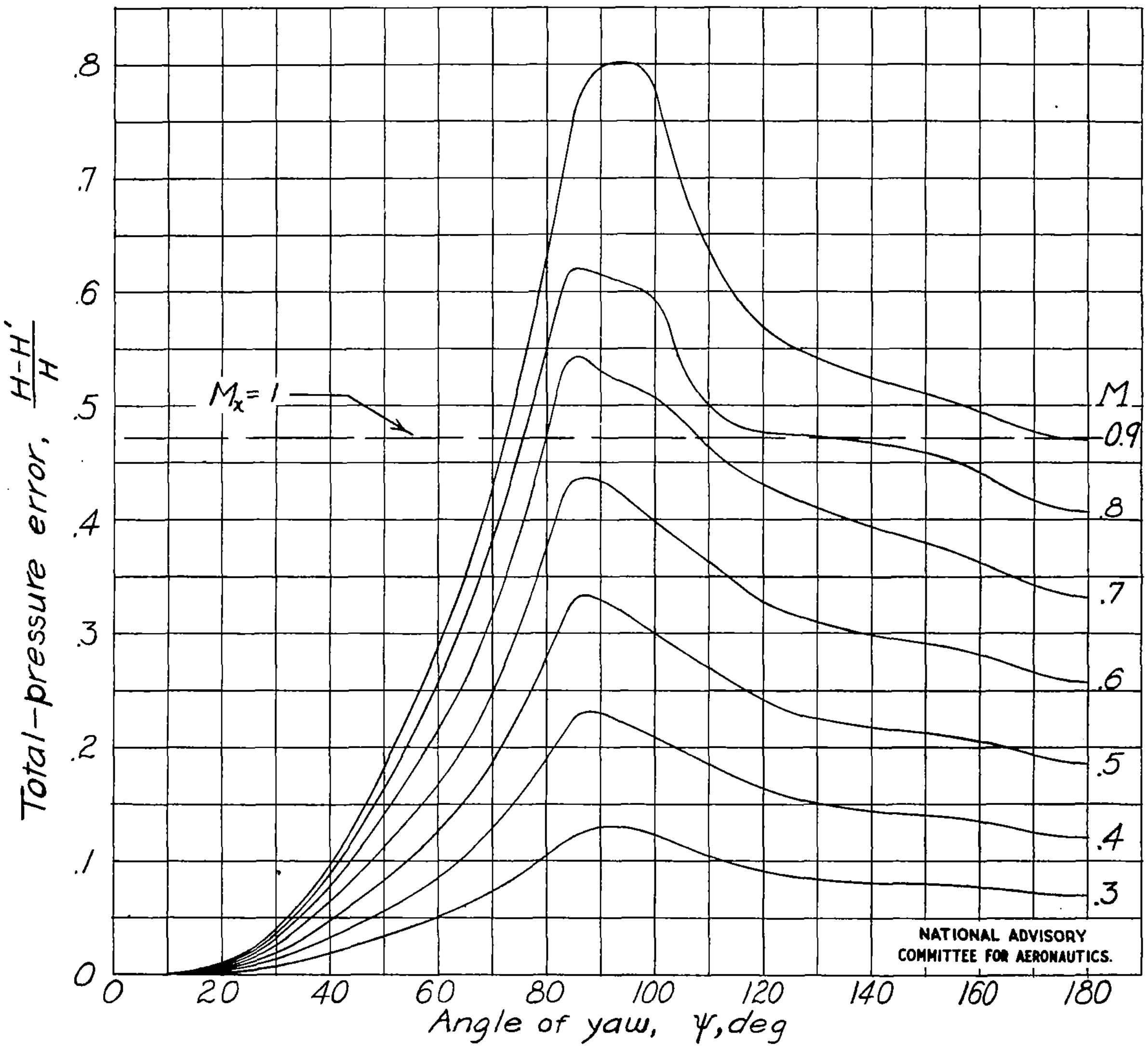
(b) Flat nose.

Figure 3.- Concluded.



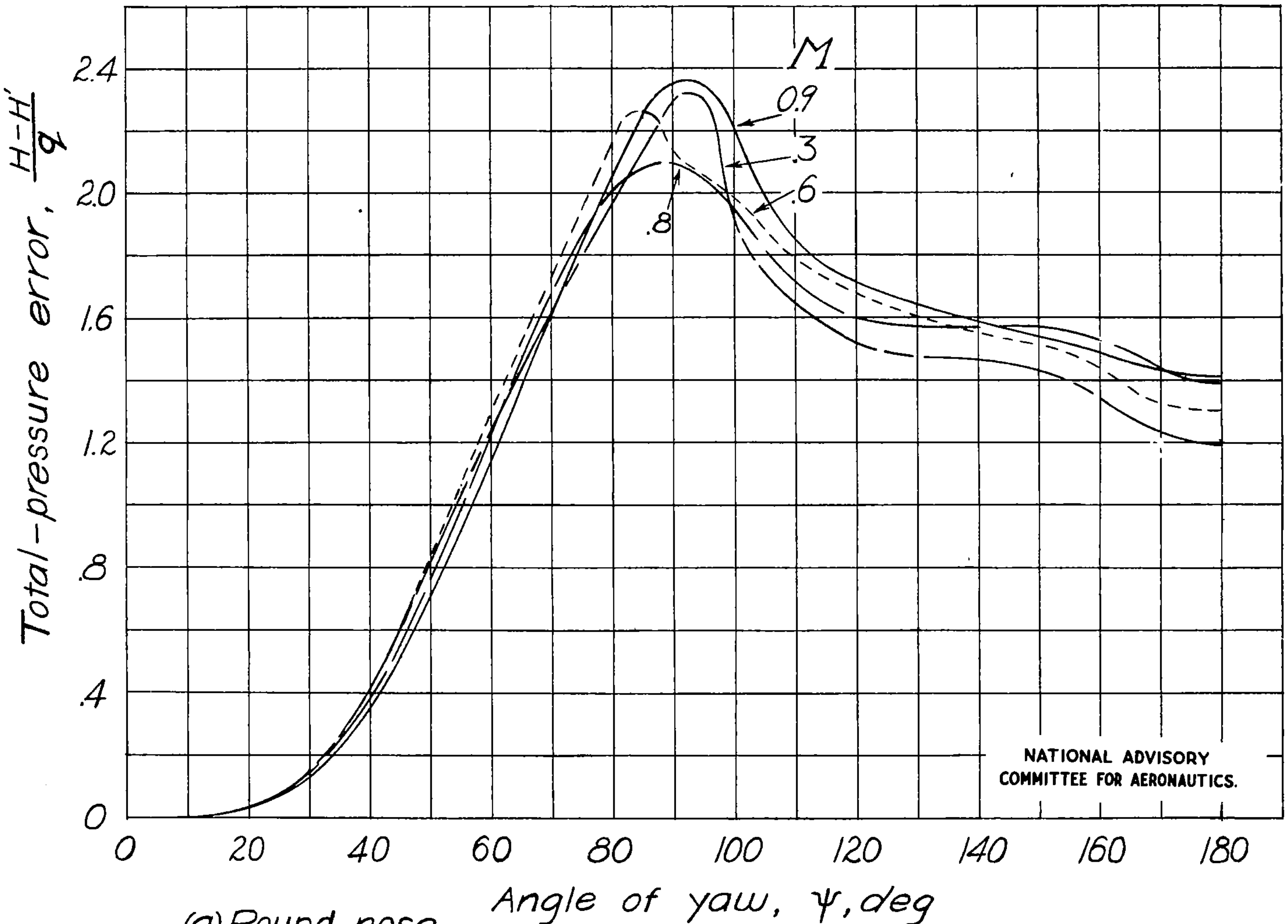
(a) Round nose.

Figure 4.- Variation of total-pressure error in terms of total pressure with angle of yaw at constant Mach number.



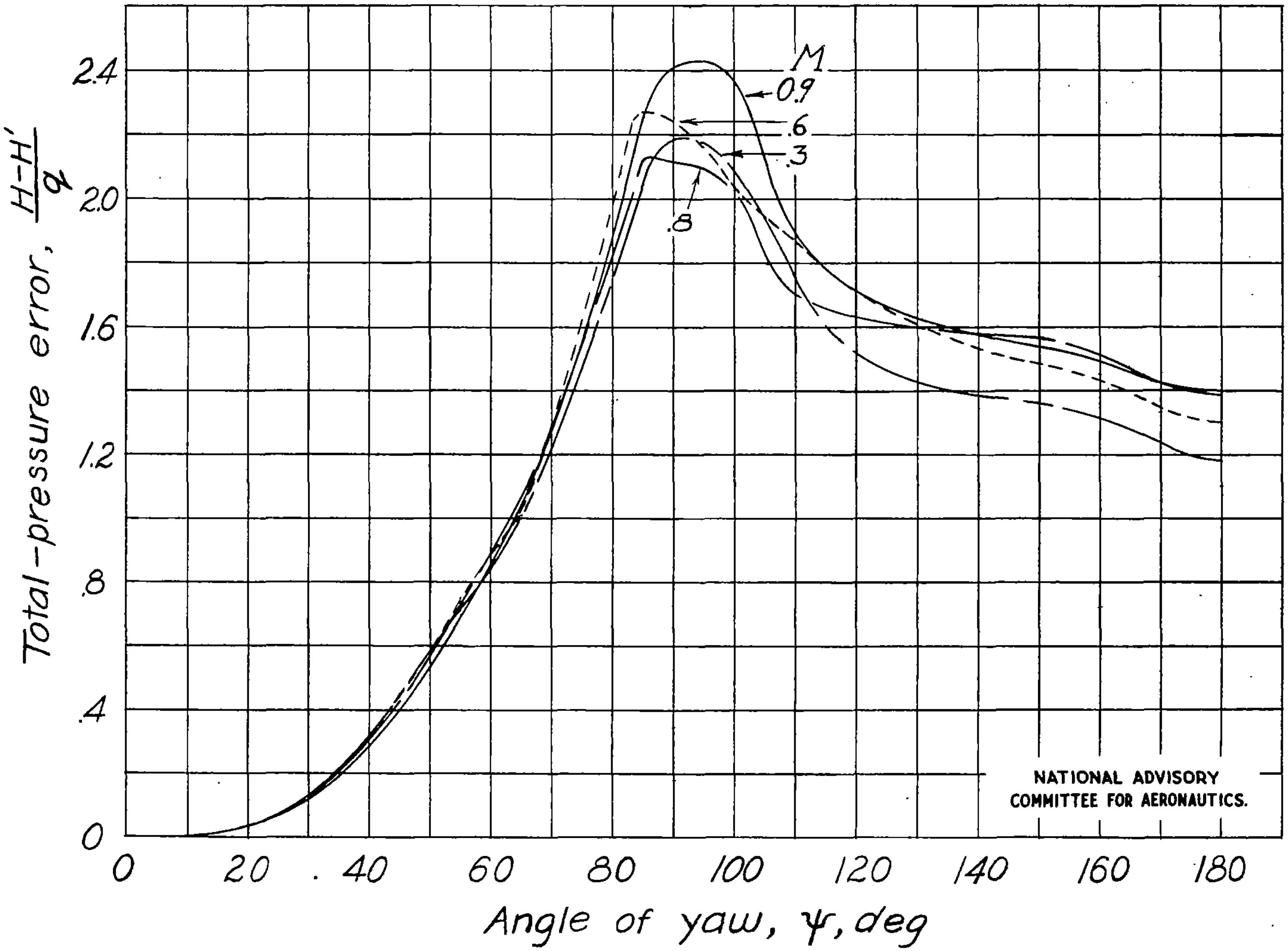
(b) Flat nose.

Figure 4.-Concluded.



(a) Round nose.

Figure 5.- Variation of total-pressure error in terms of dynamic pressure with angle of yaw at constant Mach number.



(b) Flat nose.

Figure 5.- Concluded.

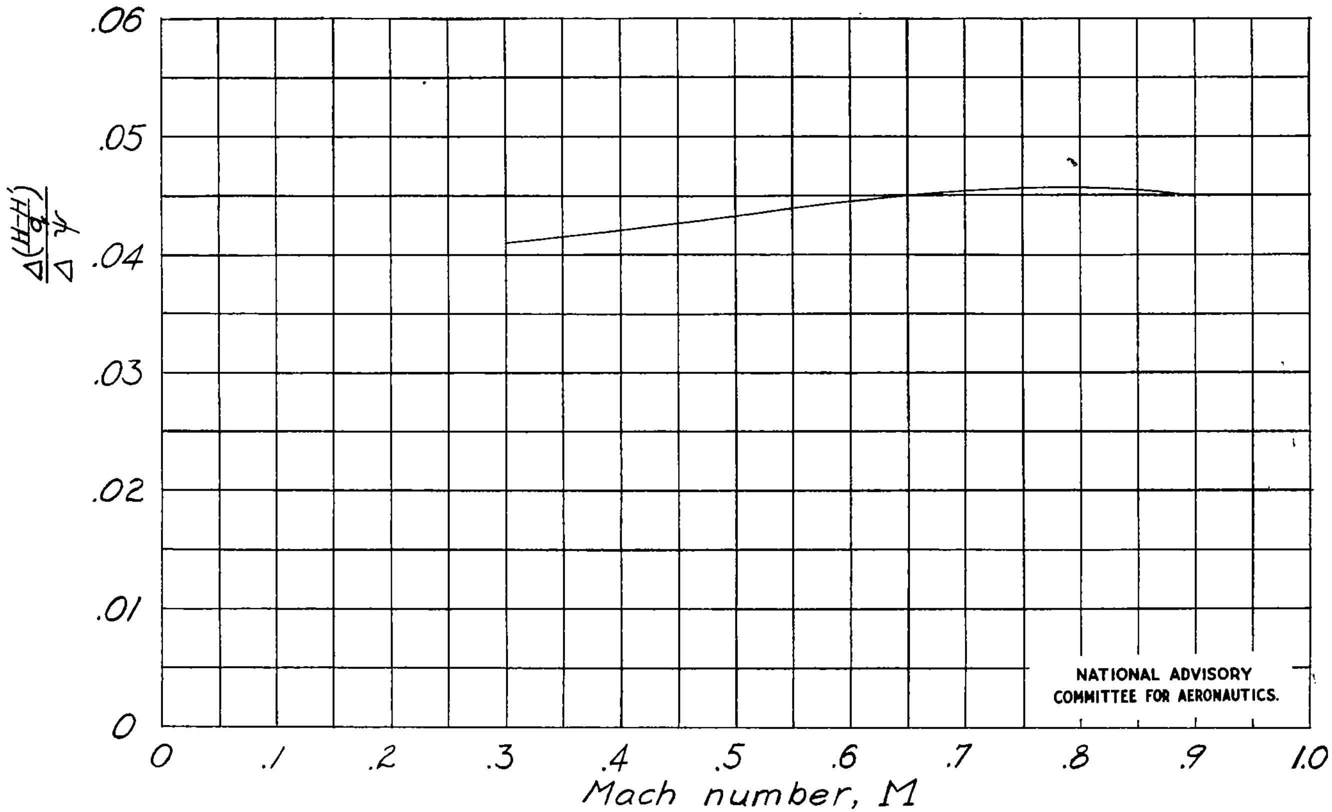


Figure 6.– Variation with Mach number of the rate of change of total-pressure error with angle of yaw for the round-nose tube. $50° < \psi < 70°$.